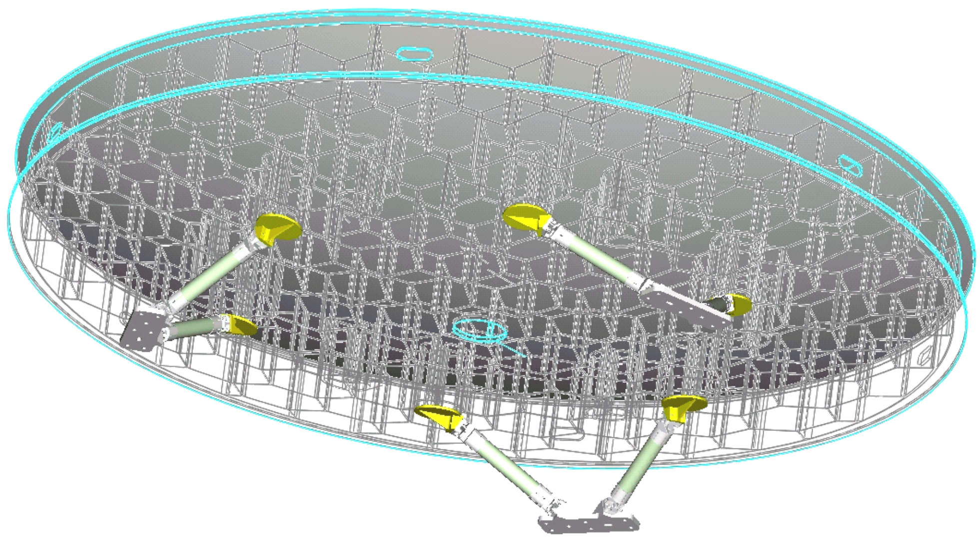
KEPLER PHOTOMETER
PRIMARY MIRROR ASSEMBLY
CURRENT STATUS



William R. Arnold
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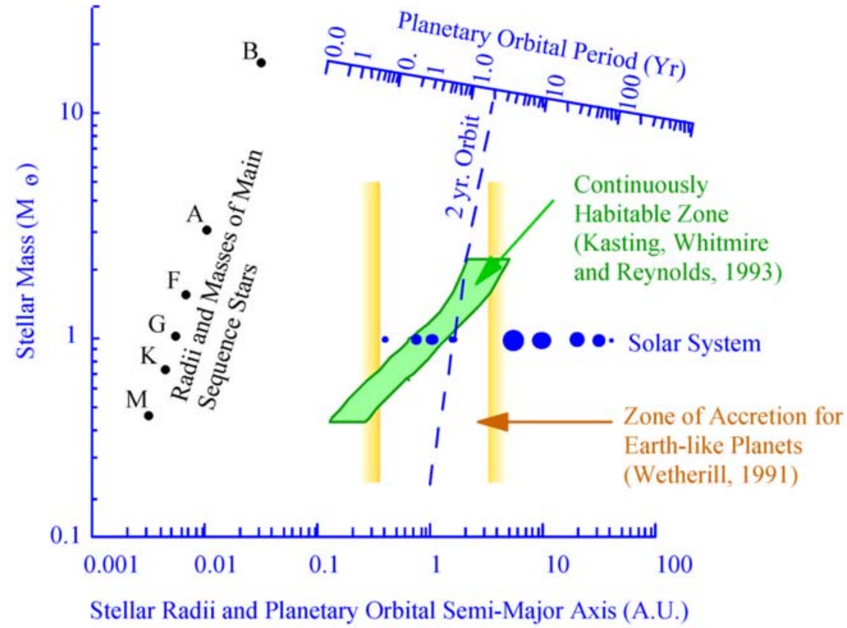
NASA Tech Days 2004

Overview

- **Brief description of Kepler Space Photometer**
- **Where L3-Brashear fits into the program**
- **Primary Mirror Assembly Design Challenges**
- **Primary Mirror Assembly Status**
- **Summary**

The Terrestrial Accretion Zone & The Habitable Zone For Various Stellar Type



Each main sequence spectral type (B, A, F, G, K, M) is shown in black to indicate the star's mass and radius on the left side of the diagram.
The Habitable Zone (green) and the planets in our solar system (blue) are shown.
The *Kepler Mission* is capable of detecting Earth-size and larger planets in orbits of up to two years.

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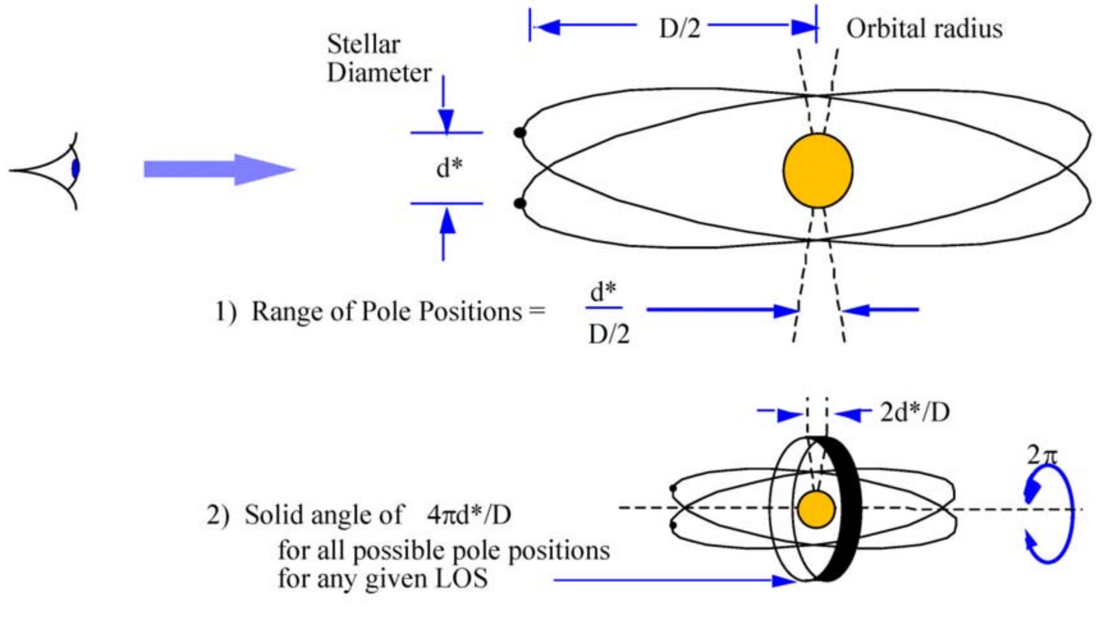
Geometry for Transit Probability



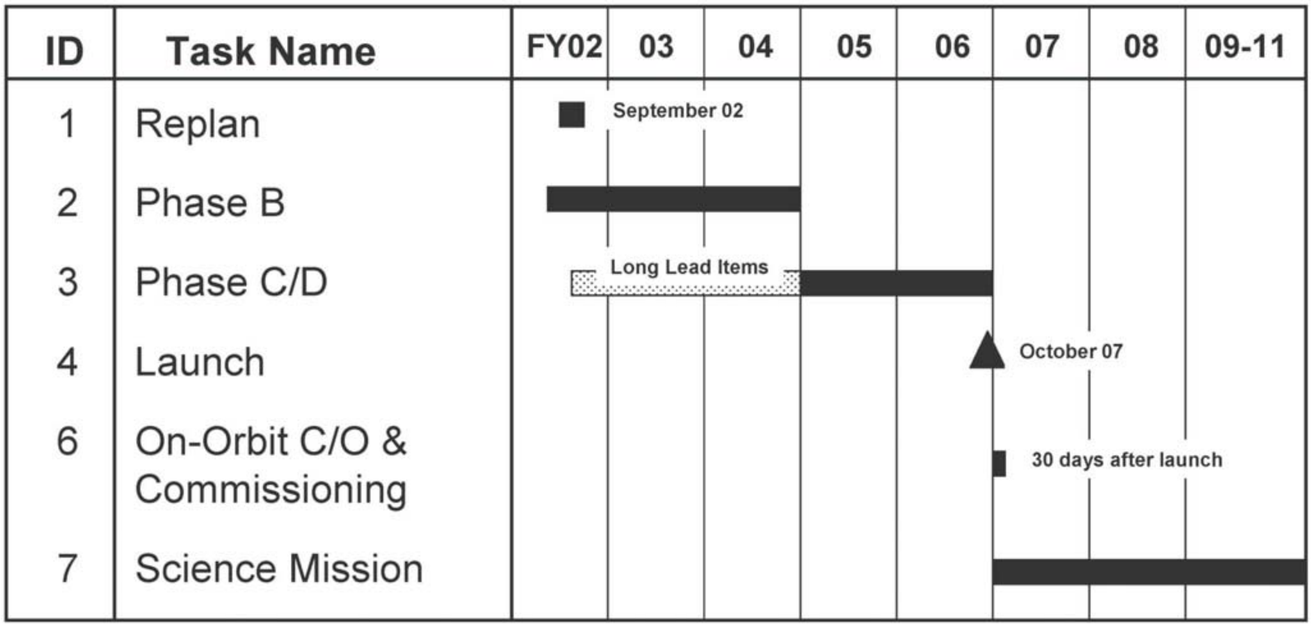
3) Geometric Transit Probability = d*/D

5/96

Day 1 (1-3)

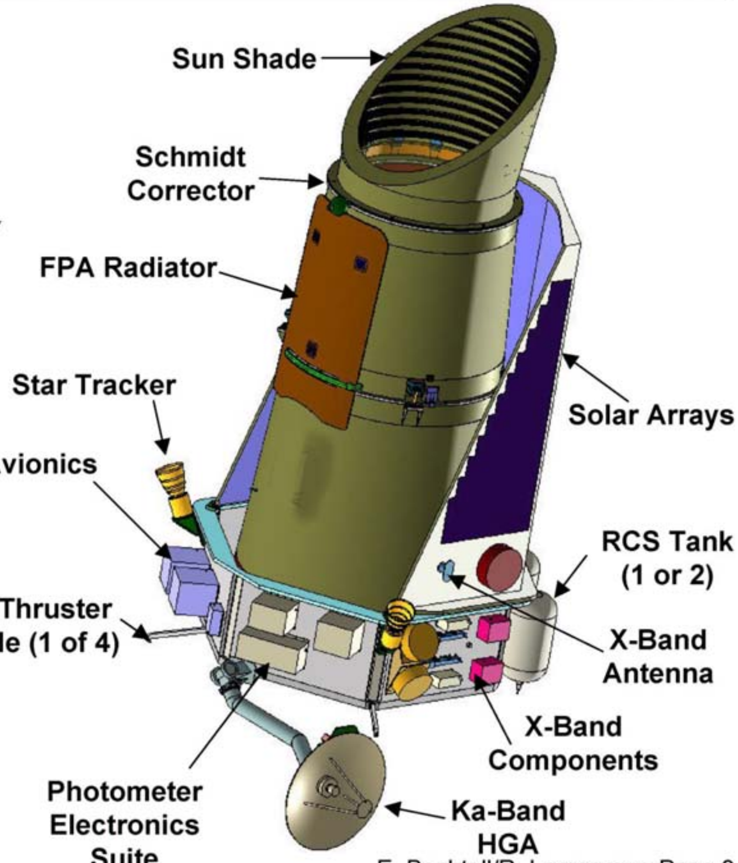
(W. Borucki) Page 6

Level 1 Schedule



Flight Segment Architecture

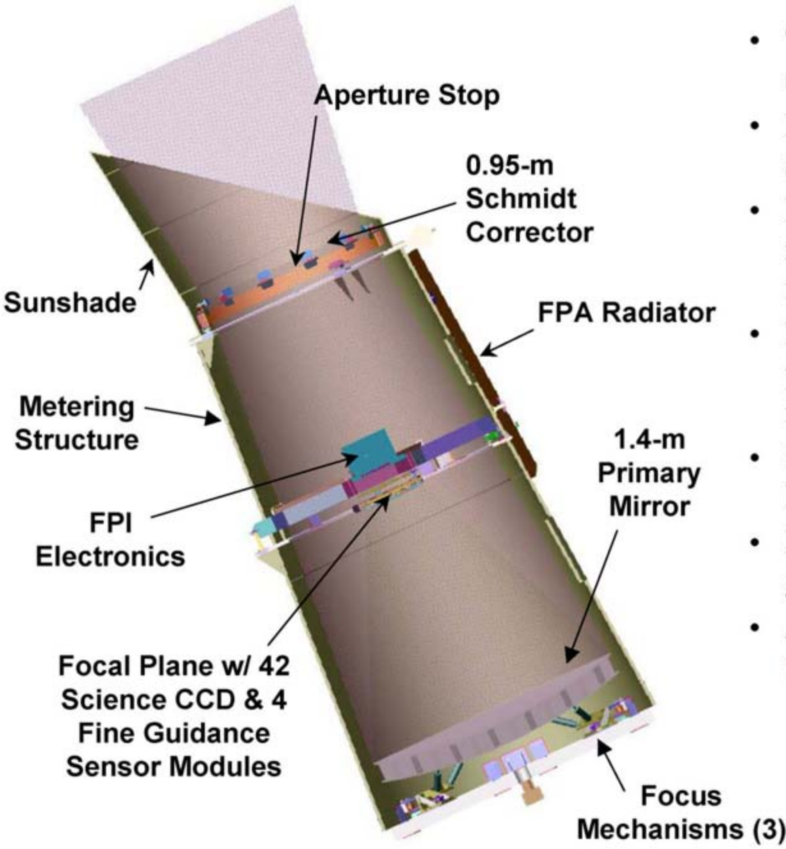
- Concurrently Collects > 170000 Photometric Targets
- Large FOV: > 100 Sqr Deg
- 84 Channel Thermally Controlled CCD Focal Plane
  - Four-fold symmetric to facilitate quarterly roll
- Large, uniform optical PSF provides accurate photometry and FPA manufacturability
- String-selectable photometer electronics
  - Graceful degradation
- Fully redundant spacecraft (except battery)
  - X-band Uplink/RT Tele Dwnlink
  - Ka-band Stored Tele Dwnlink
  - Cold gas RCS
- Fine guidance sensors integral with photometer's focal plane allows exceptional attitude accuracy and stability
  - Ties attitude control to instrument boresight



Day 1 (1-9)

E. Bachtell/R. Lampereur Page 3

Photometer Architecture



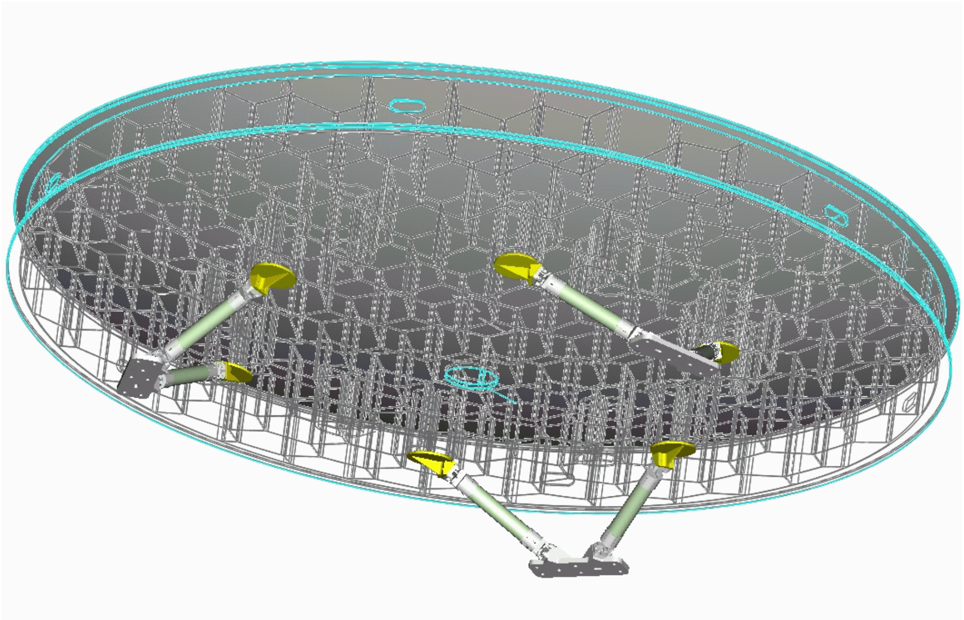
- Two additional electronic boxes mounted to spacecraft (CSP and RPE)
- Focal plane operated at –95° C reduced dark signal and radiation degradation effects
- Field flattener lenses integral to CCD modules provides bandpass filters and CCD radiation protection
- Focus mechanisms at primary mirror mount provide focus / tip-tilt correction for metering structure CTE/CME effects
- Stray-light controlled by baffled GFCE honeycomb metering structure
- Exterior MLI blankets control thermal gradients on optics
- Active heater control on focal plane controls focal plane to ±0.1° C.

Day 1 (1-9)

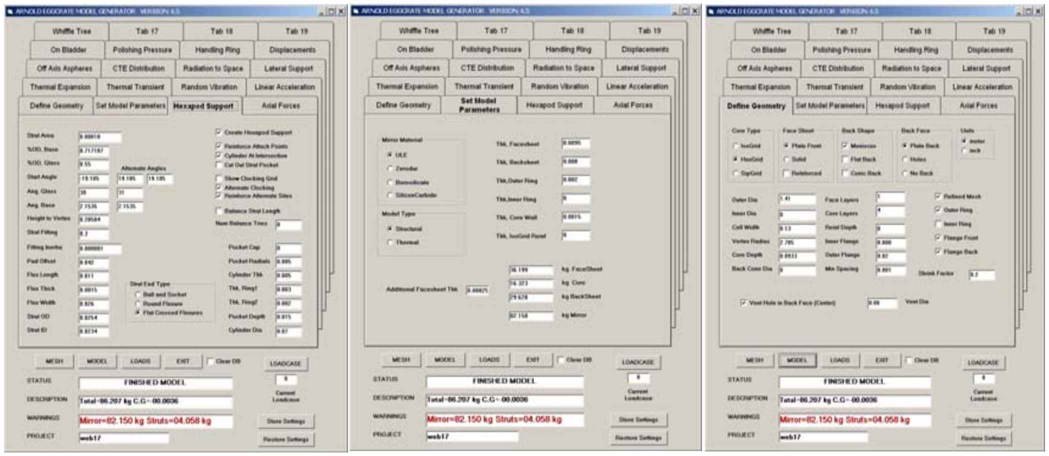
E. Bachtell/R. Lampereur Page 6

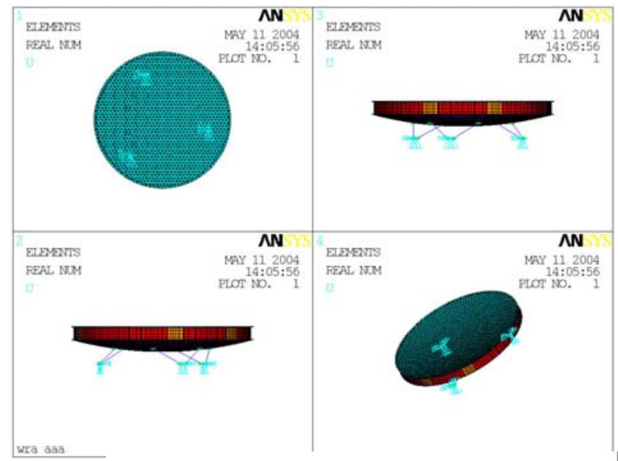
Key Features Which Make Kepler PMA Unique

- Systems approach to Primary Mirror Assembly design
- Accommodating broad operating temperature range and high stiffness
- Including alternate support attachment locations
- Integral design features to accommodate lifting, handling, tooling, metrology & coating



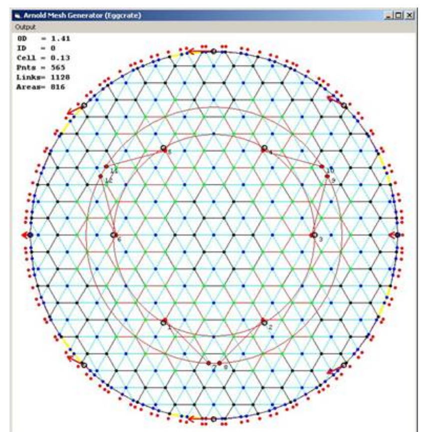
Custom engineering tools stream line the design process

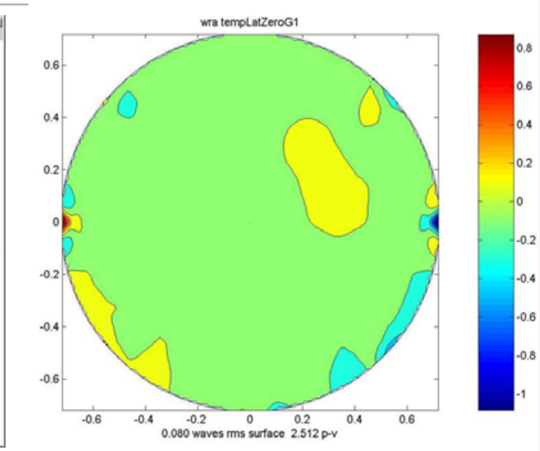




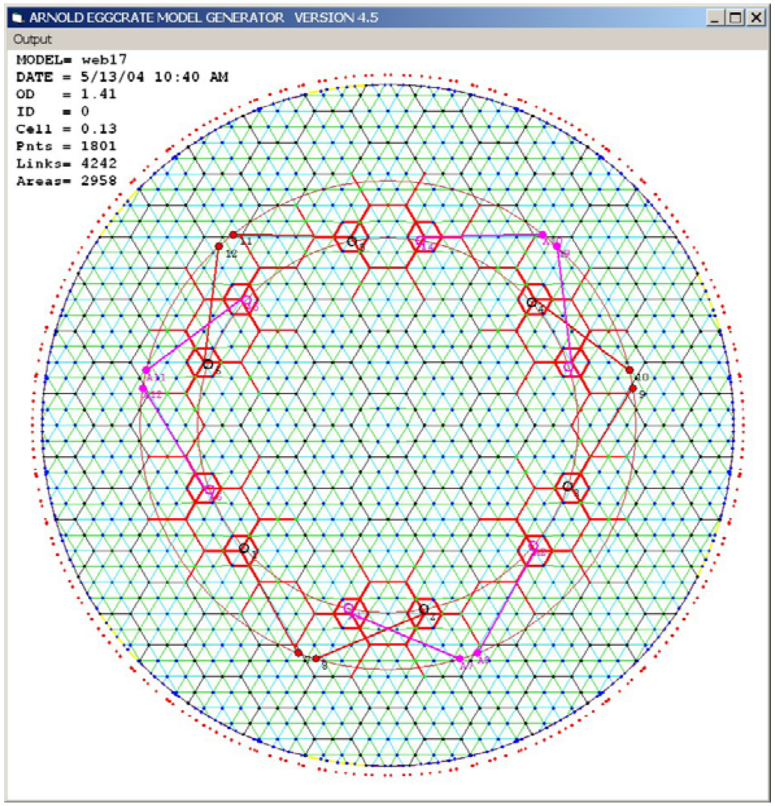
Specialized software allows the consideration of most aspects of the complete mirror fabrication and test cycle at the same time the traditional launch and operational performance is analyzed.

Complete design iterations can be completed in under an hour, including handling and test setups.





Risk Mitigation: Alternate Attachment Location



Bipod Leg Geometry

Start Glass 19.105 | Start Base 19.105 | Ang Glass 30.000 | Ang Base 2.154

Strut Length	0.27301	0.27299	0.27301	0.27299	0.27301	0.27299
@Pad Angle	60.769	60.766	60.769	60.766	60.769	60.766
PlanView Angle	241.037	337.172	121.037	217.172	1.037	97.172
Glass Radius	0.39716	0.39716	0.39716	0.39716	0.39716	0.39716
@Foot Angle	62.158	62.156	62.158	62.156	62.158	62.156
Spread Angle	48.068	48.067	48.068	48.067	48.068	48.067
Foot Spread	0.01900					
Foot Offset	0.50526					

MODEL= web17

DATE= 5/13/04 10:40 AM

Alternate Bipod Leg Geometry (0)

Start Glass 19.105 | Start Base 19.105 | Ang Glass 31.000 | Ang Base 2.154

Strut Length	0.27299	0.27301	0.27299	0.27301	0.27299	0.27301
@Pad Angle	60.766	60.769	60.766	60.769	60.766	60.769
PlanView Angle	202.828	298.963	82.828	178.963	322.828	58.963
Glass Radius	0.39716	0.39716	0.39716	0.39716	0.39716	0.39716
@Foot Angle	62.156	62.158	62.156	62.158	62.156	62.158

MODEL= web17

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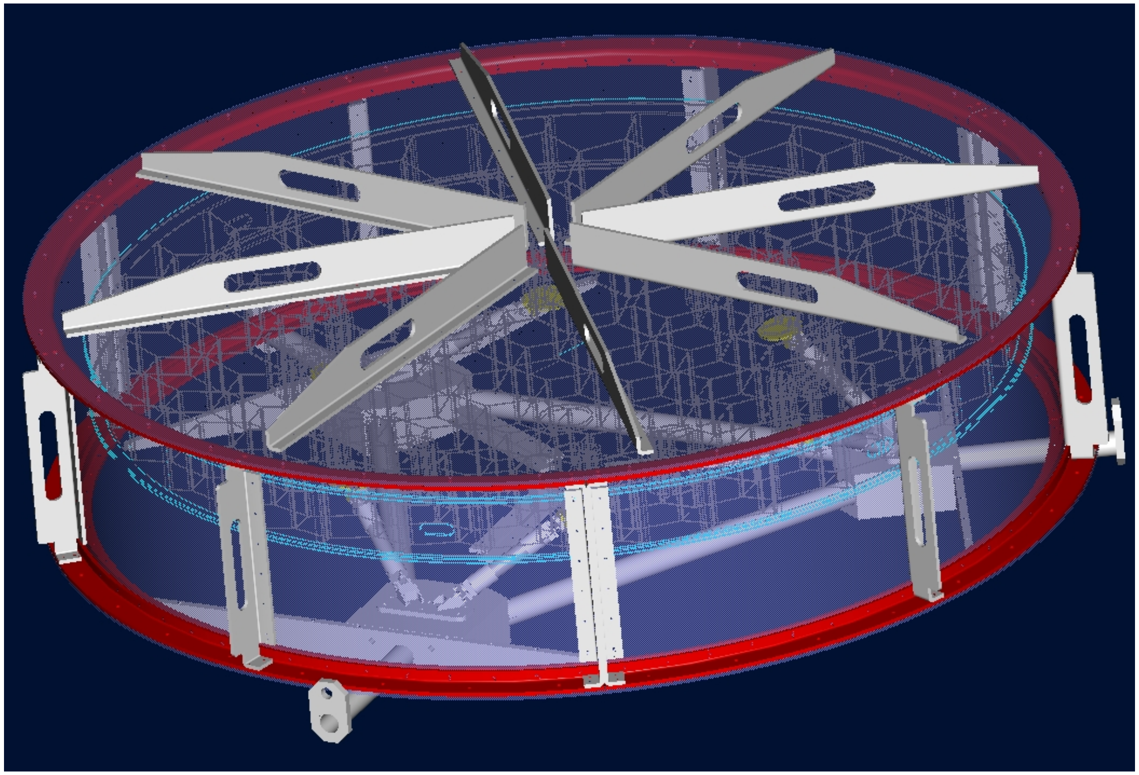
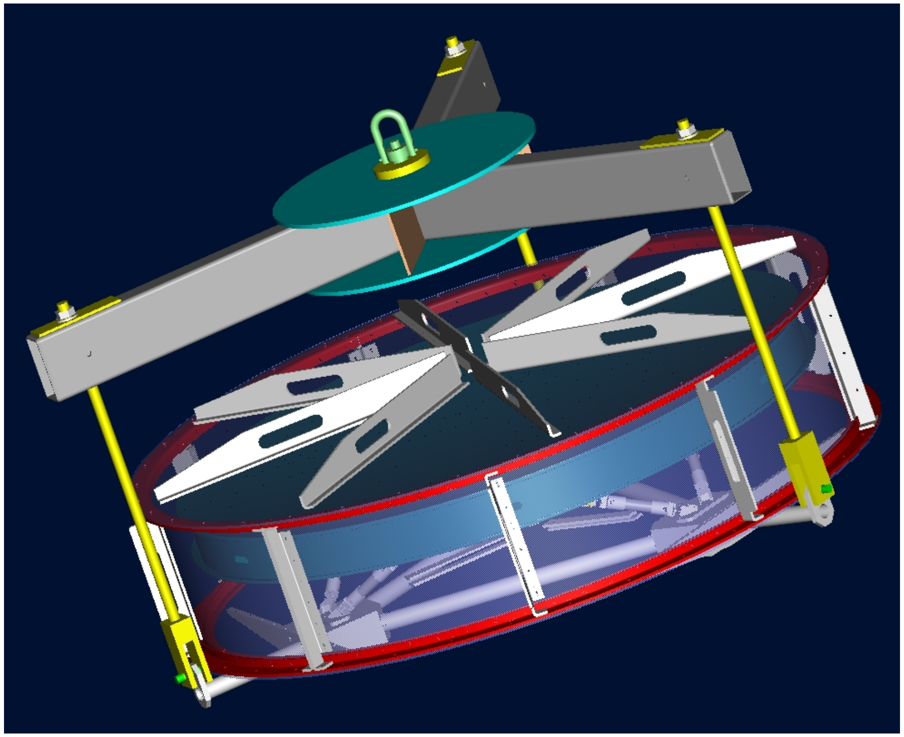
Design tool was modified to locate alternate locations on the mirror where the attachment leg geometry matches the primary attachment sites. The design tool then generates the appropriate reinforcement patterns.

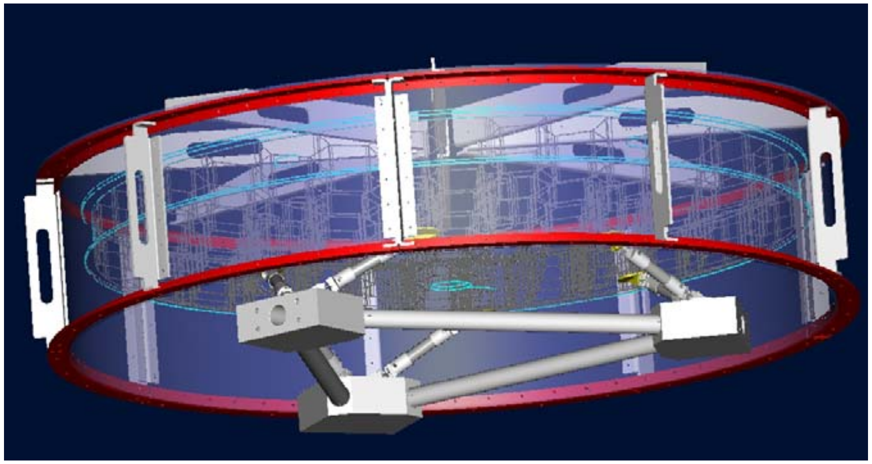
Shielding Attached to Strongback



Protection of the optic during all stages of manufacture, assembly and testing is important. The design and ease of installation and removal of the shields is evaluated using Pro/Engineer models.

Versatile Tooling approach

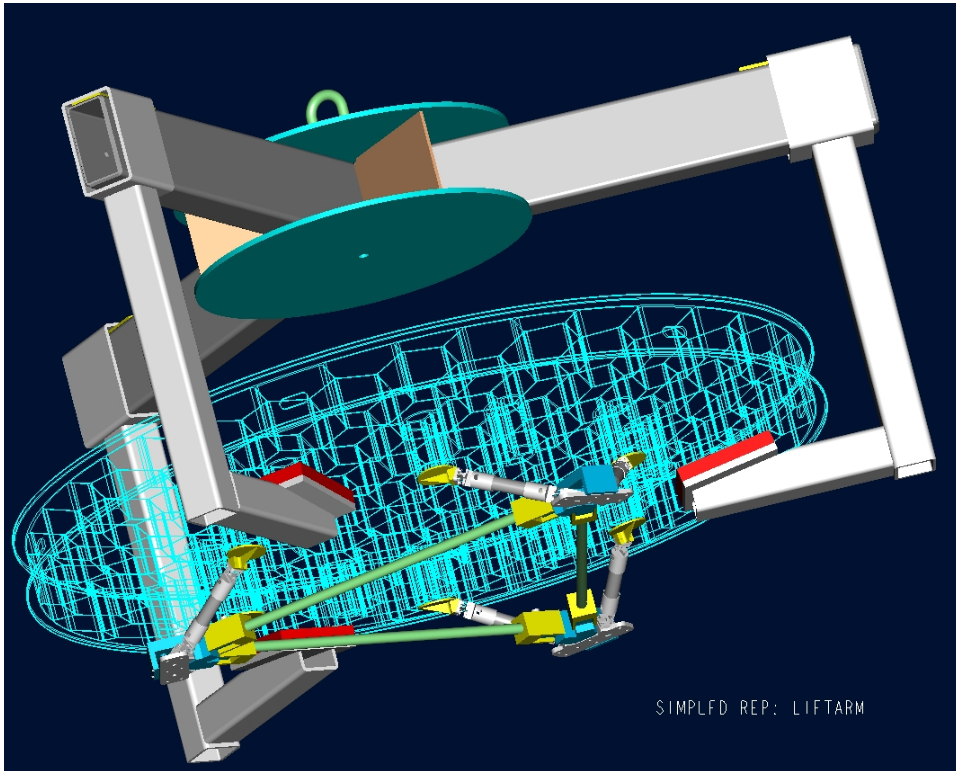




Portion of tooling useable during vibration tests

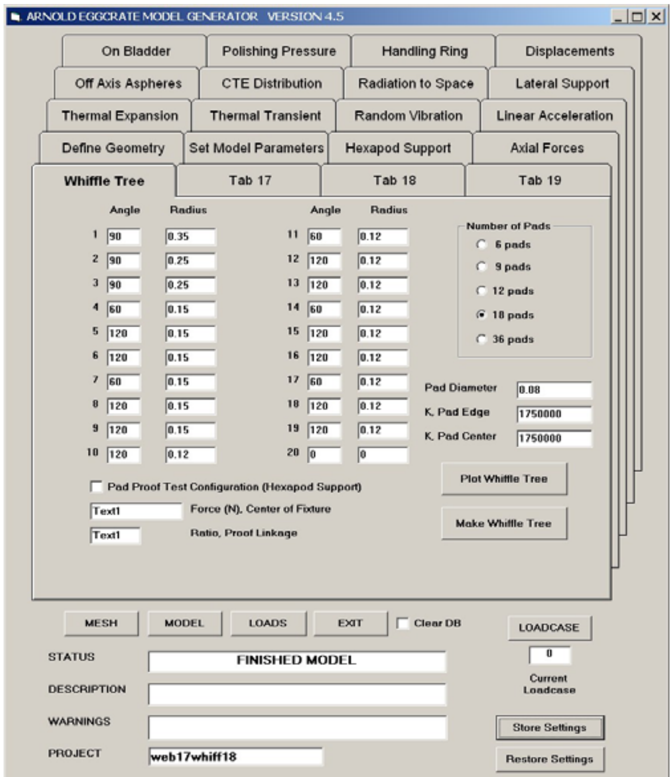
All tooling is designed as part of a complete manufacturing and handling plan.

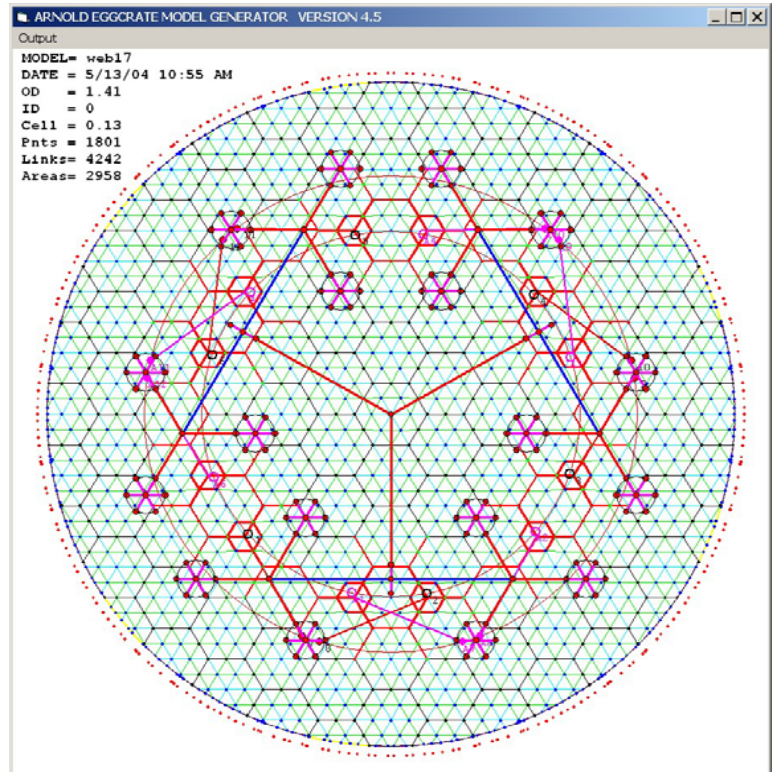
Configured to Transfer PMA



Each step in the integration cycle requires planning and tooling. The transfer of the Primary Mirror Assembly from its shipping and test support (strongback) to the satellite is one of these critical steps. The flexures in the suspension system must be protected and the overall alignment of the assembly maintained throughout the transfer operation.

Integrated Design of Proof Test Fixtures





The design tool had a generalized whiffle tree axial support system design option. This capability was expanded for Kepler to include the use of a whiffle tree reaction system during bond pad proof testing. To minimize the non-symmetric loads into the mirror, all six attachment pads are proof tested simultaneously.

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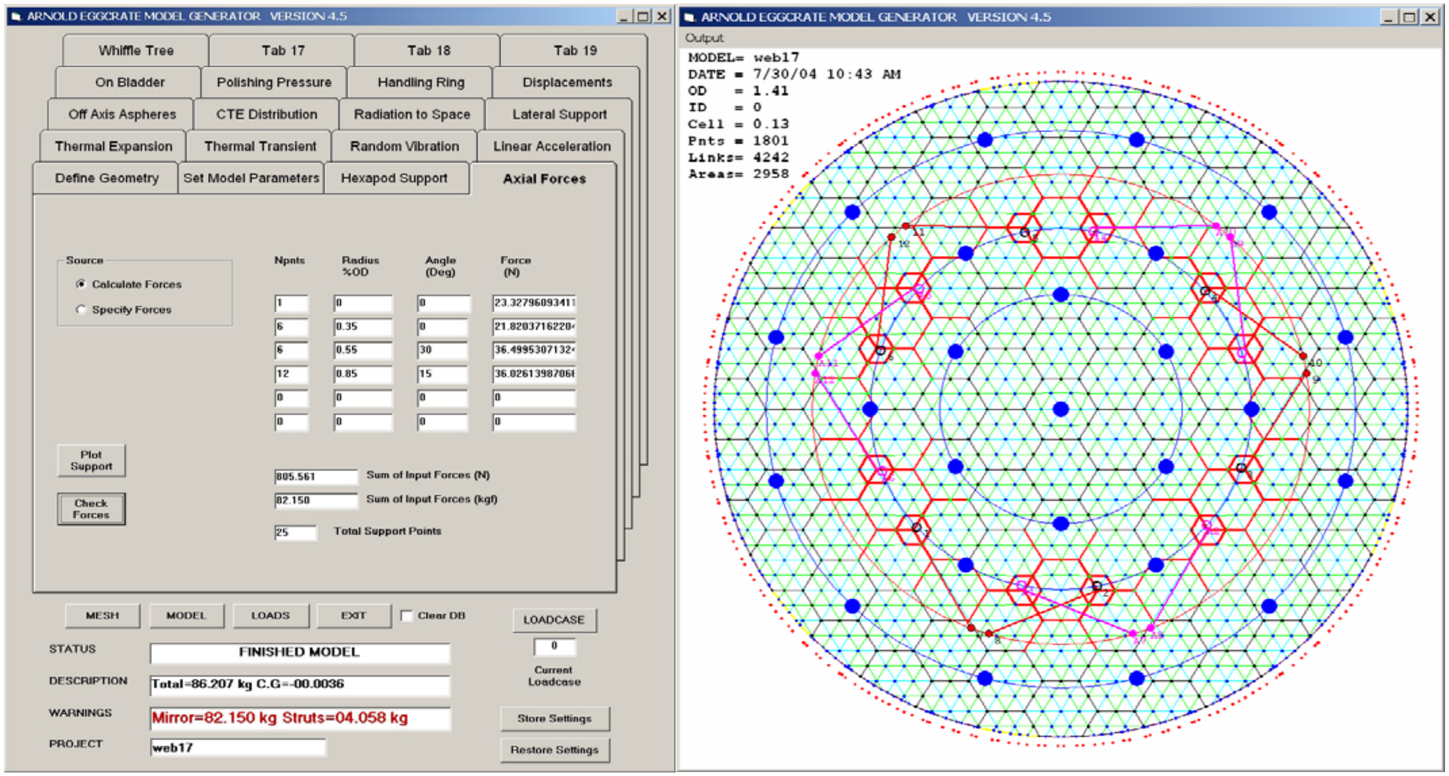
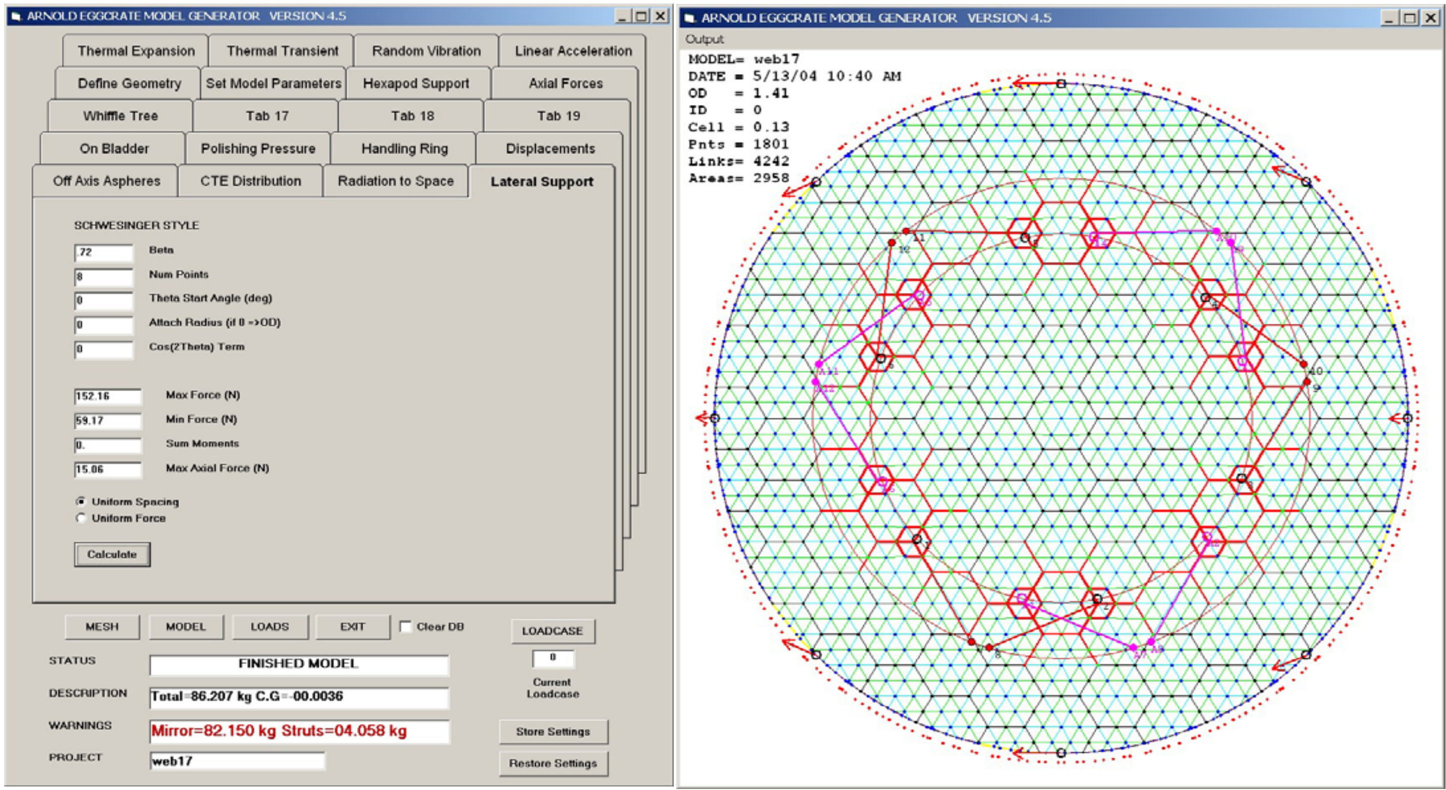
Integrated Design of Axial Test Supports



Design tool allows rapid evaluation and design of optical axial test supports (zero gravity simulators). Both mirror bonded assembly and full suspension system configurations can be modeled in the same analysis runs. The analyst can specify forces or let the program calculate appropriate distributions.

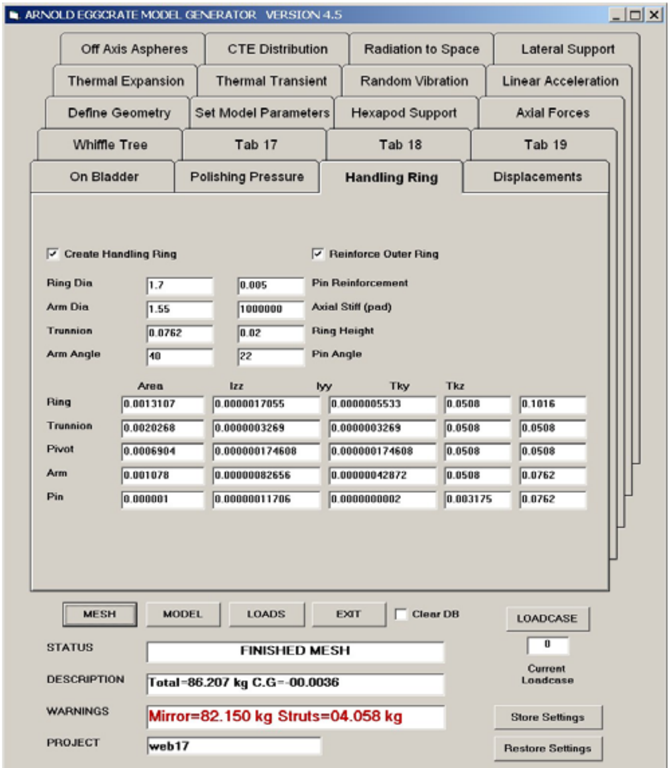
Kepler

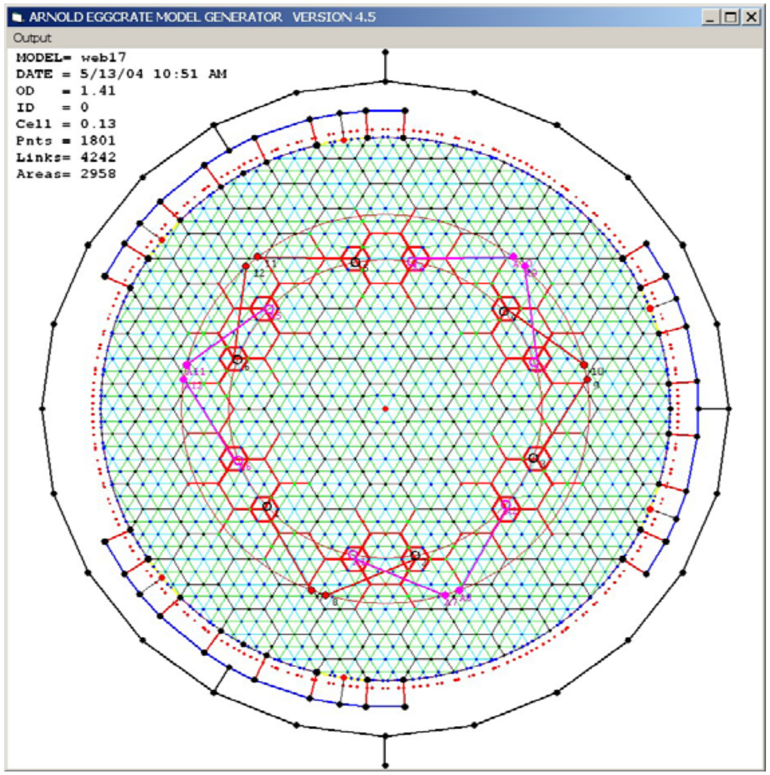
Integrated Design of Lateral Test Supports



Design tool allows rapid evaluation and design of optical lateral test supports (zero gravity simulators). Both mirror bonded assembly and full suspension system configurations can be modeled in the same analysis runs. The analyst can specify forces or let the program calculate appropriate Schwesinger distributions or classical cosine distributions.

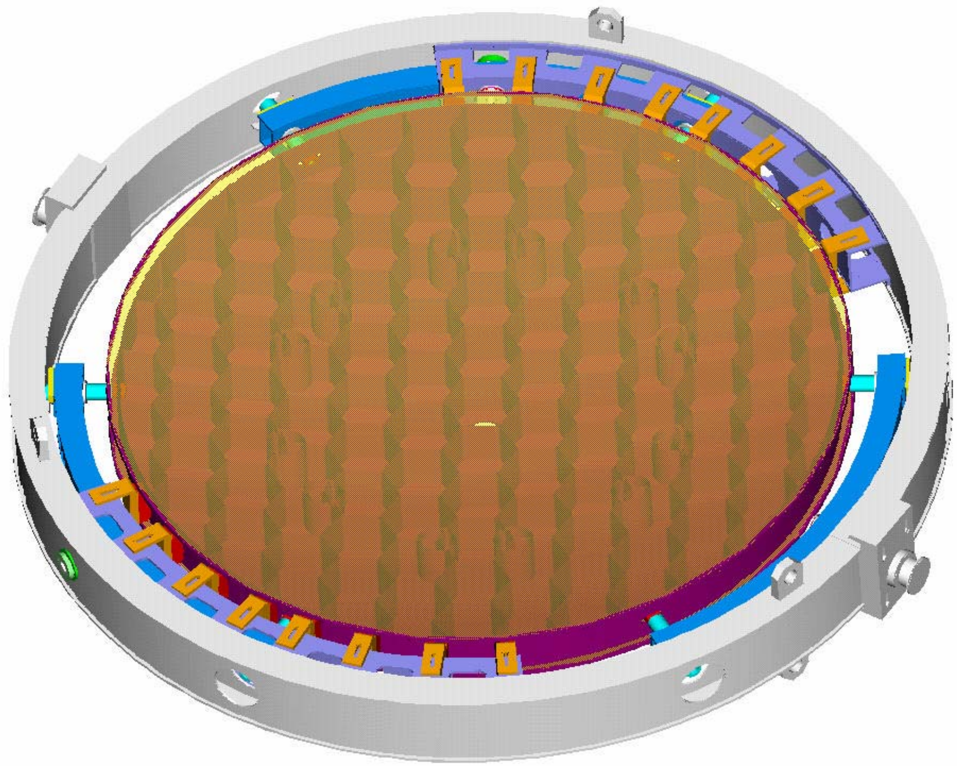
Integrated Design of Handling Equipment





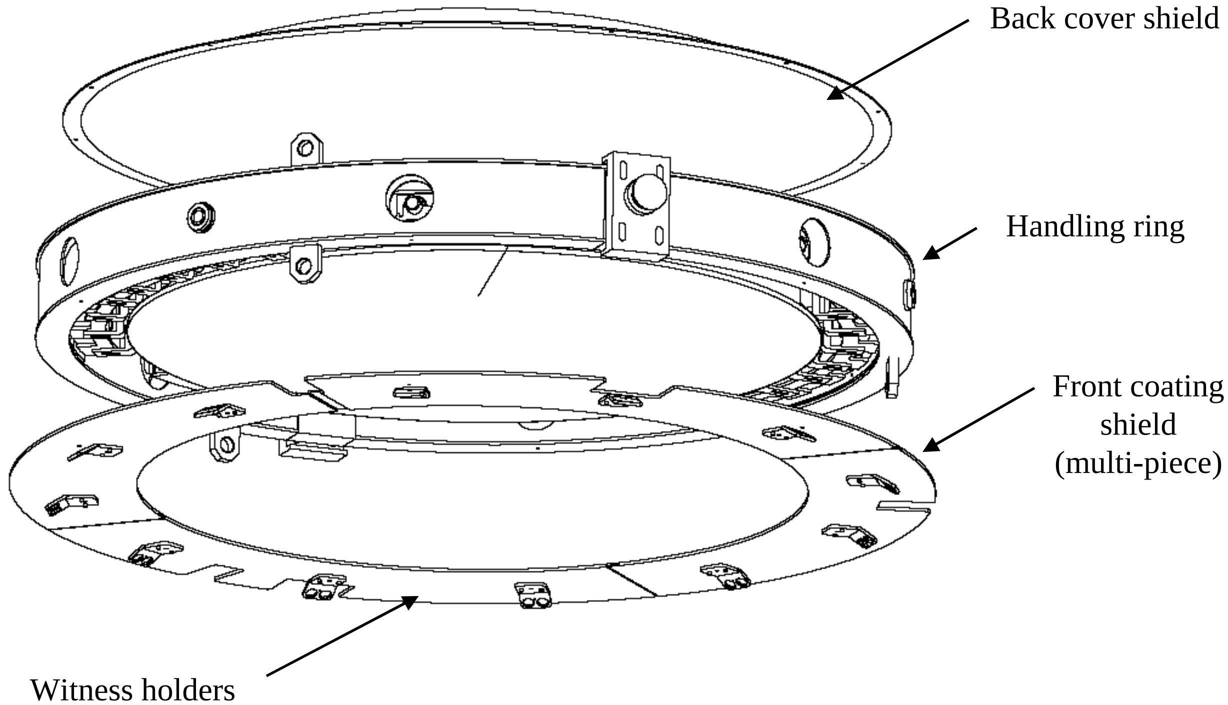
Design tool allows evaluation and design of handling fixtures during the preliminary design of the mirror blank. As mirrors become lighter, the difficulties of handling the glass during manufacturing requires careful attention to these operations. Special reinforced features were added to the blank specifically to aid the manufacturing process and reduce risk.

Primary Mirror in Flipping Ring



The handling ring interfaces with special reinforced slots in the mirror core. With the addition of storage shields, the unit can act as a temporary container. Does not touch optical surfaces or fragile edges.

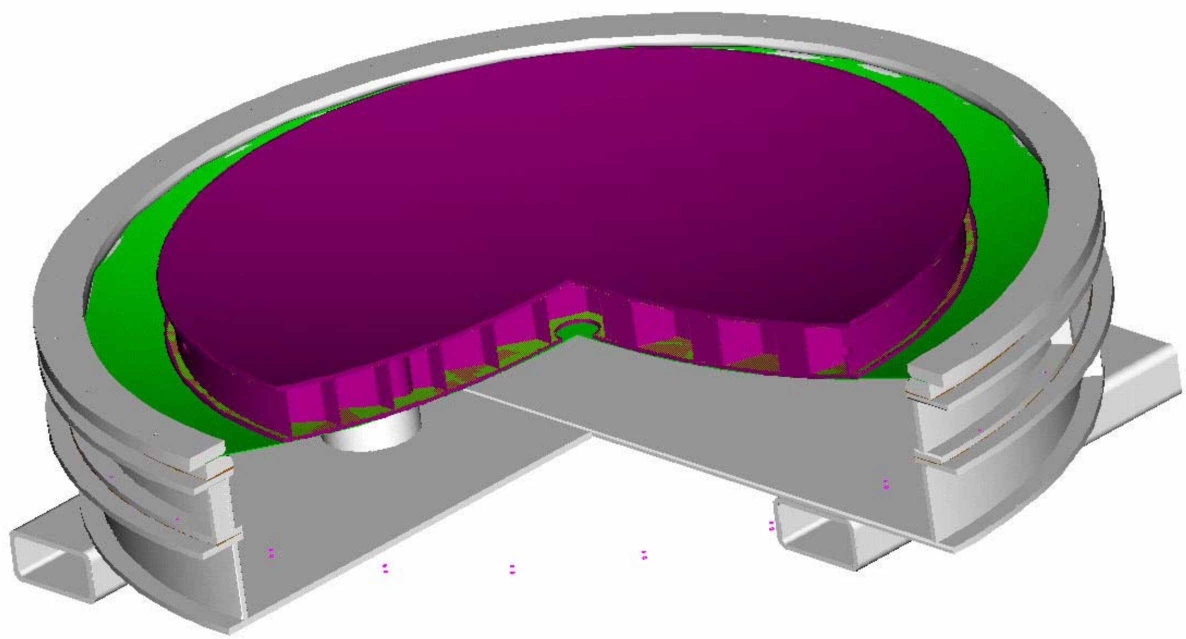
Modifying Handling Ring For Coating



The Brashear handling ring will be used as the cleaning and coating tool by OCLI.

An aluminum surrogate mirror will be used to qualify the handling procedures and personnel of both companies. Schedule may dictate building two copies of the ring.

Primary Mirror on Air Bladder

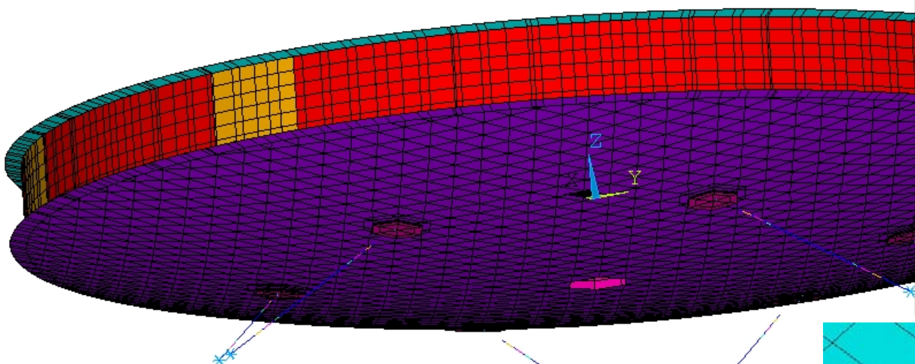


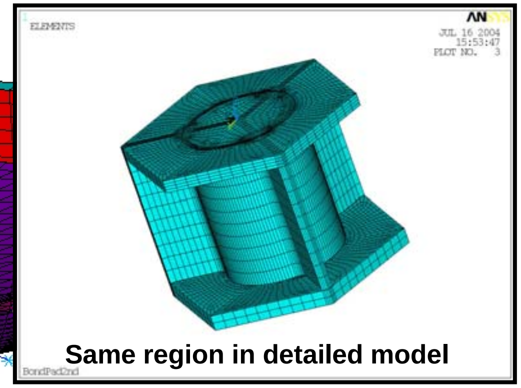
Even simple traditional optical test setups can present challenging handling problems and require additional equipment. Once the final figure is achieved, traditional vacu-lift moves become undesirable.

WHAT WE ARE CURRENTLY DOING

- **Designing, building and testing handling equipment**
- **Creating and validating procedures and processes.**
- **Designing building and testing optical test supports**
- **Refining and "fine tuning" cryogenic performance predictions and integrating into manufacturing (figuring) process**

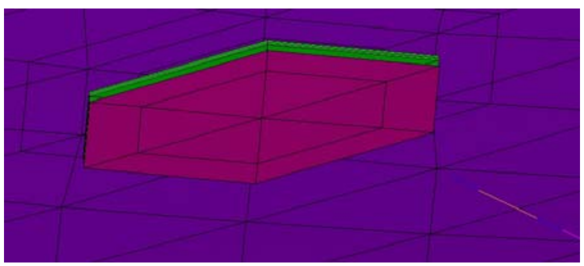
For global figure, must match refined and coarse models



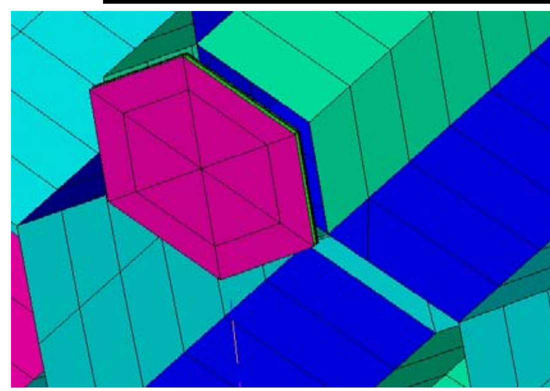


Same region in detailed model

Typically 30,000 to 50,000 Elements



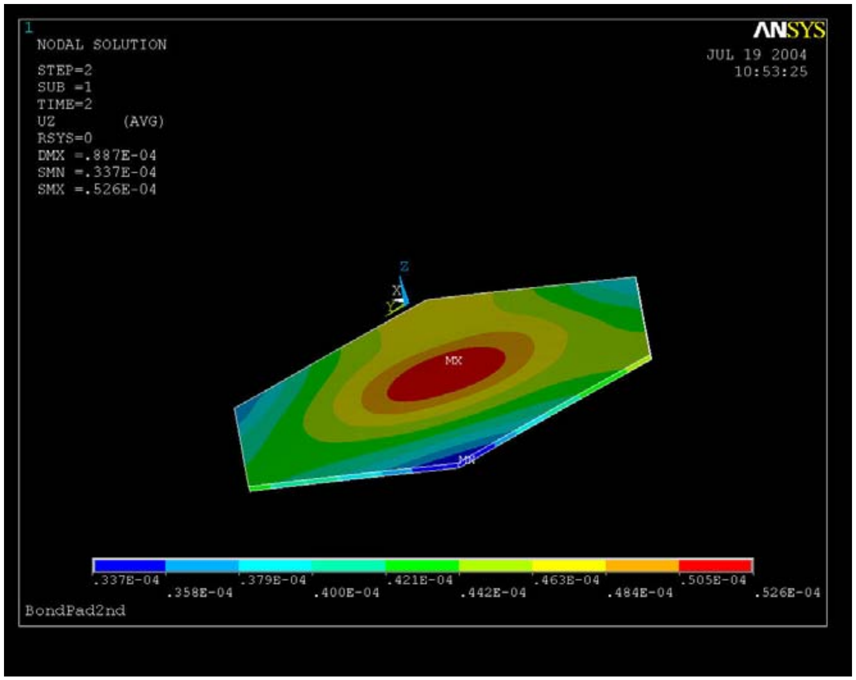
Close up of bond pad and adhesive

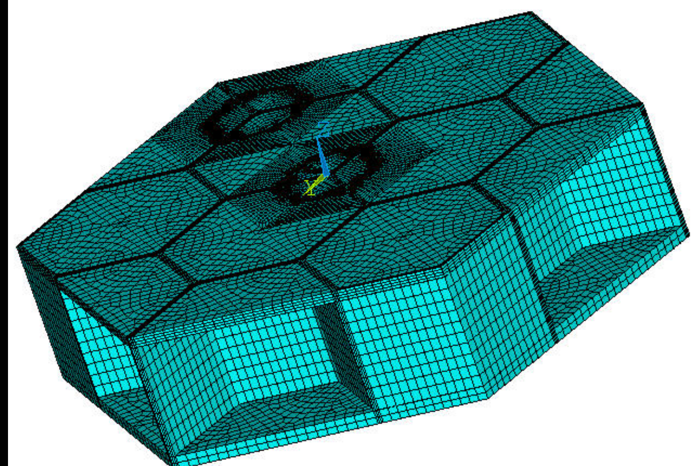


Back sheet removed to show core structure

The original "standard model" created by the Eggcrate modeler has been enhanced to include several bond pad configurations to match both cell centric and web intersection reinforcements schemes. The coarse model is only used for distortion (global figure) analysis and mirror-suspension dynamics.

Local refined model of bond pad region





Typically 400,000 to 500,000 Elements

To investigate the highly localized stresses in the region of the bond pad, a detailed model of the region was constructed. The ANSYS model can be re-meshed and geometry modified parametrically to investigate glue and pad variations. The optical surface side of the model is used to match the influence of adhesive shrinkage and CTE differences. The model includes the frit layers, adhesive layer and the reinforcement cell geometry. The bond pad has two relative orientations to the cell pattern in the global mirror.

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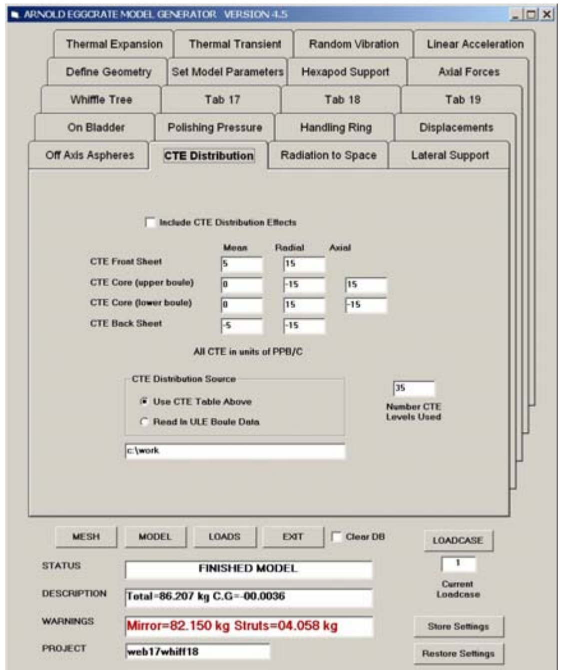
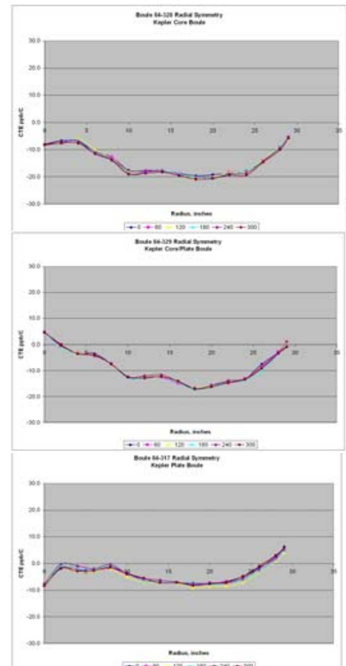
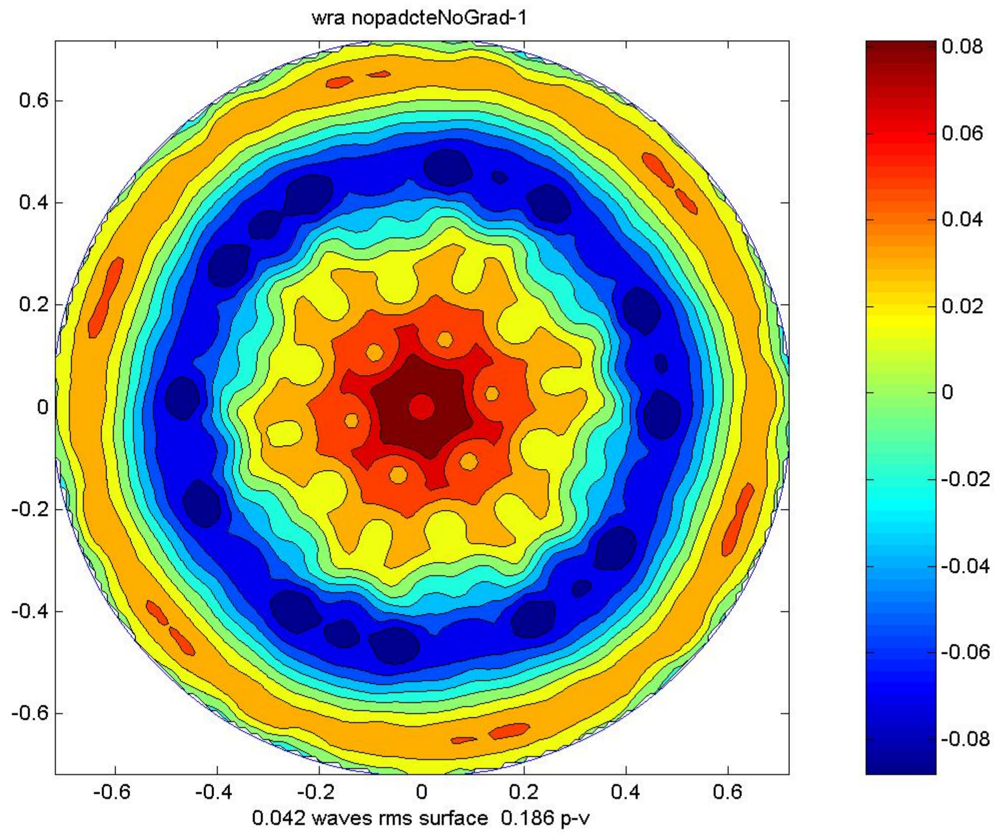
Specialized Studies and Capabilities





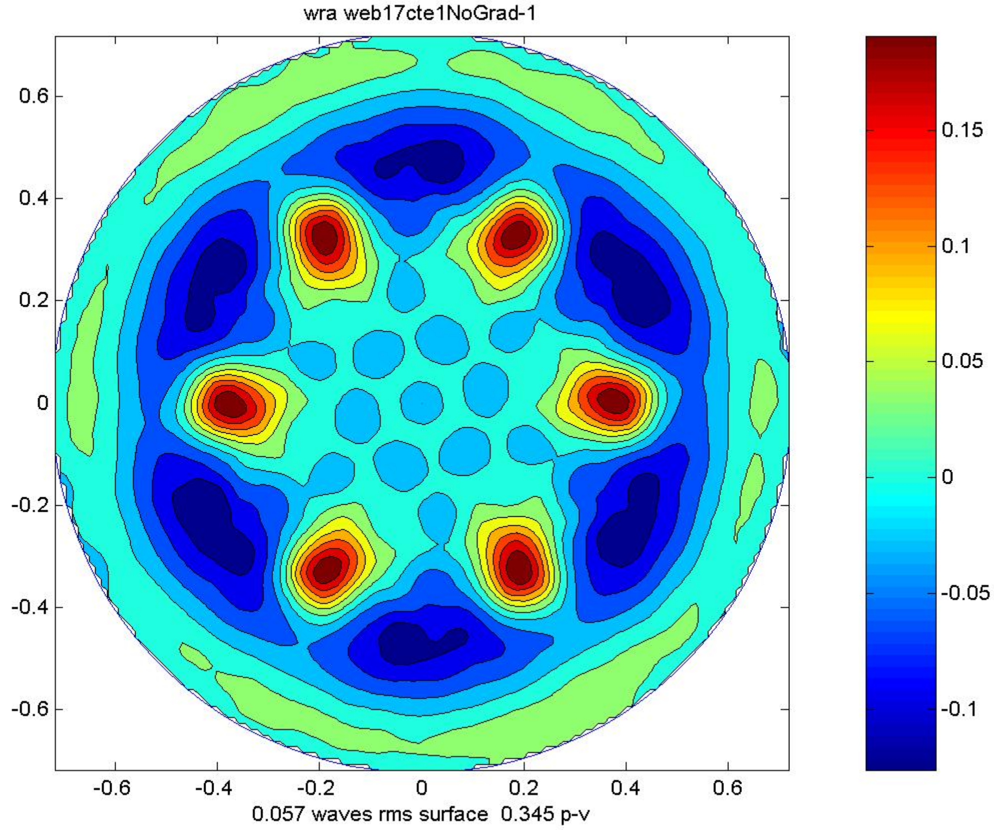
CTE distributions in mirror substrates has always been an important design consideration. Our original meniscus model generator had extensive capabilities for mapping CTE characteristics of boules from the Subaru 8.3 meter days. For TPF and SBL studies, this mapping was incorporated into the Eggcrate modeler as well. The actual boule CTE distributions are three dimensionally mapped onto the elements of the model. Using this approach allows a clearer understanding of the interaction of actual thermal gradients with material distributions.

As-built predicted figure at -60° C (without bond pads)



The cryogenic figure has two components, the effect of material (CTE) non-uniformity and the effects of the bond pads CTE mismatch. To help understand the relative contributions, analyses were run with and without the pad contribution.

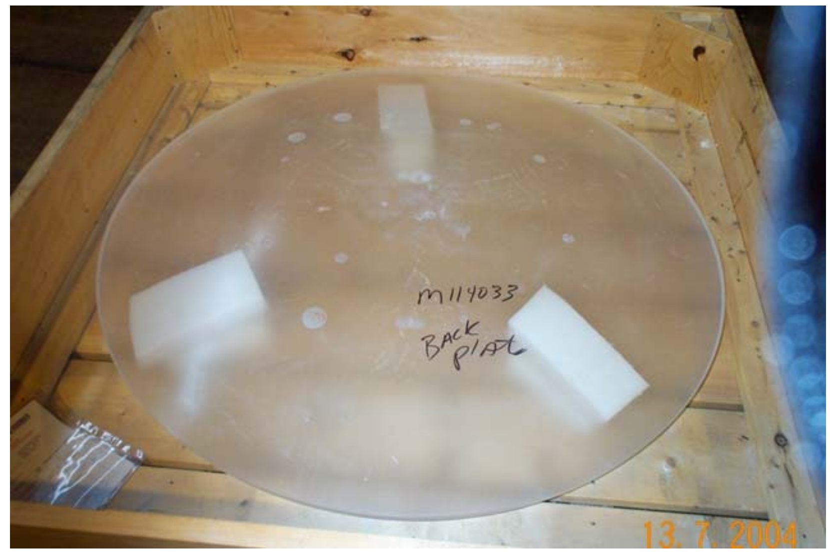
As-built predicted figure at -60° C (with bond pads)



The material constants of the global model have to be adjusted to produce the same local deformation pattern (amplitude of the hill) as the detailed model. A percentage of this prediction will be figured into the mirror. Cryogenic optical testing will validate the results.

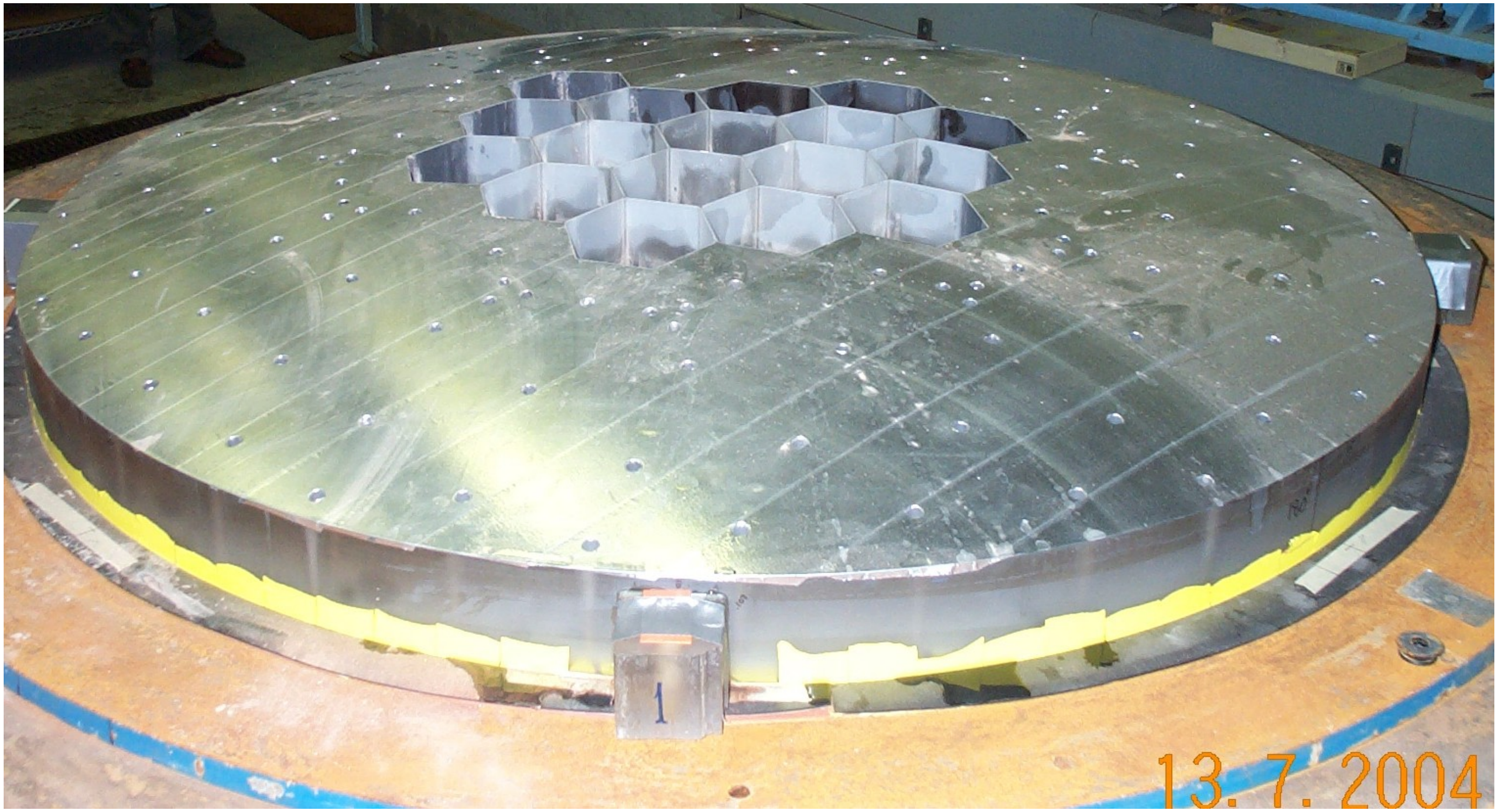
CURRENT MANUFACTURING STATUS

Front face sheet ready for final grinding

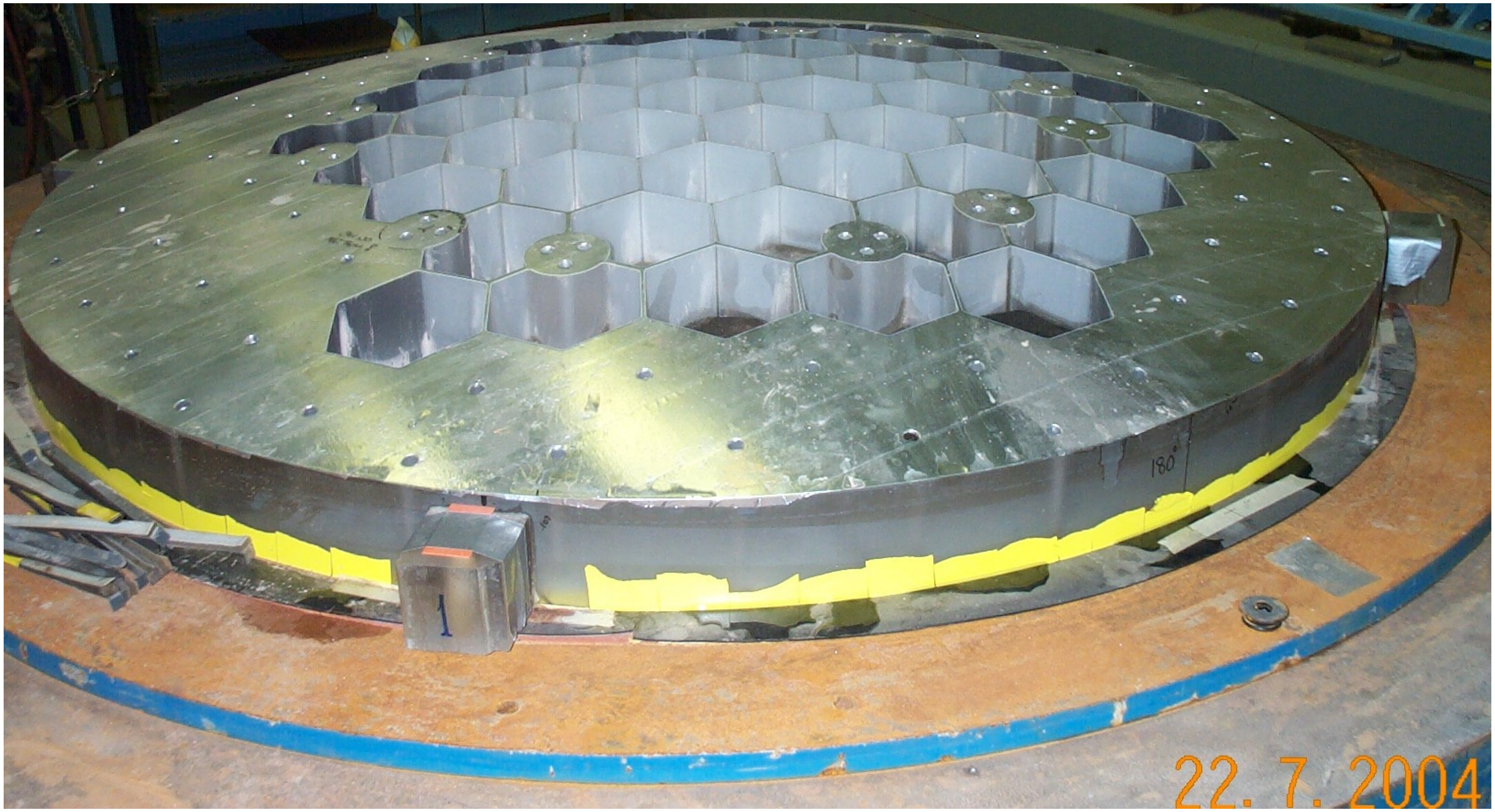


Back face sheet ready for final grinding

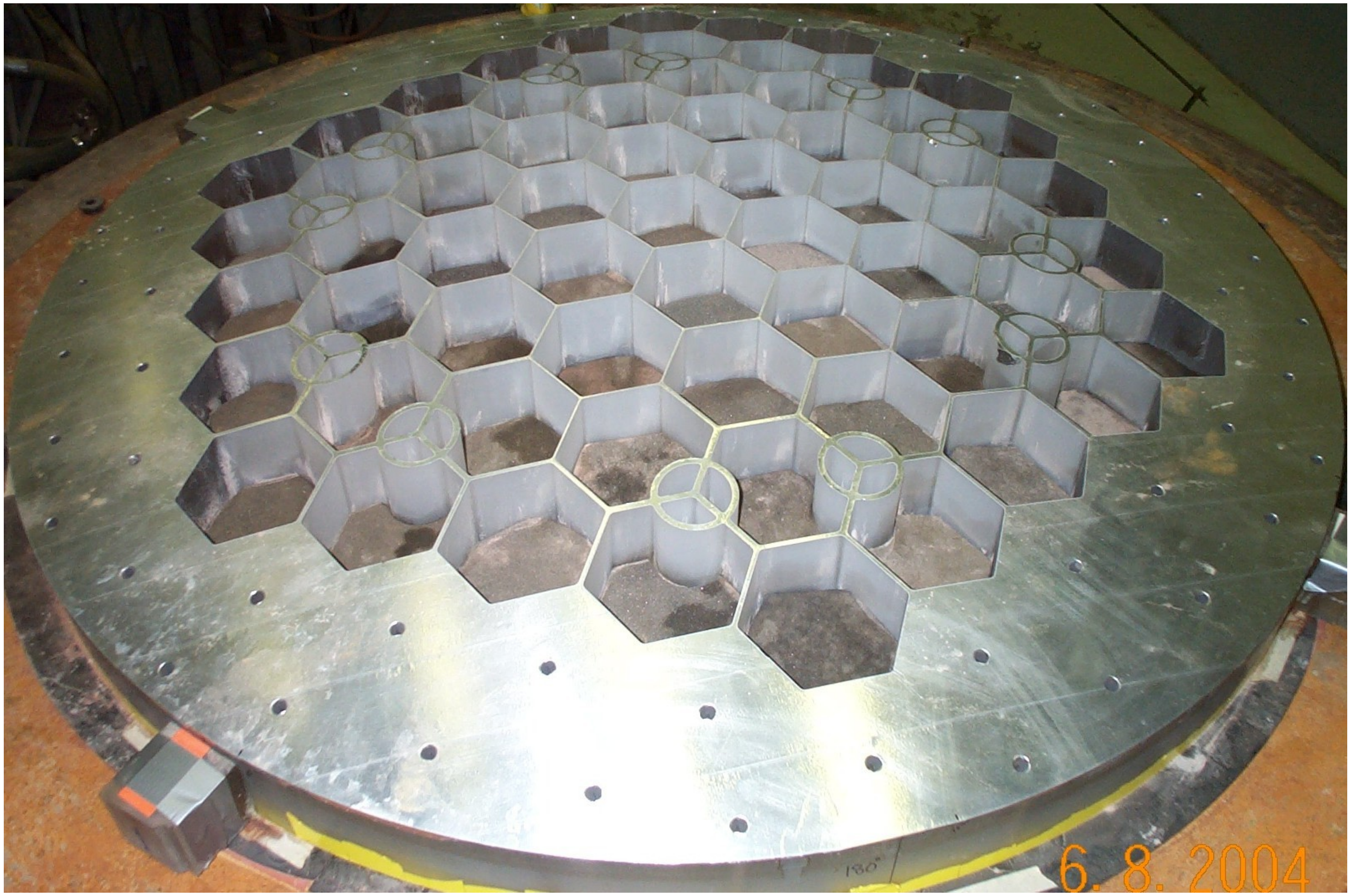
Core early in waterjet process



Some of the local reinforcement features visible



Into the home stretch



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SUMMARY

- CTE Issues addressed by specialized analysis tools and three dimensional measurements of "as built" mirror (raw boules + waterjet cores).
- Lightweight ULE mirror blank in production currently, scheduled for delivery to polisher early 4^{th} Qtr of this year.
- Suspension System components in early phases of protoflight development and testing.
- Most test fixtures and production tooling designed and currently in fabrication/assembly stage.